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OVERVIEW ARTICLE

On several issues regarding efforts toward a sustainable society

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Abstract Environmental issues and the future sustainability of society are among the greatest concerns facing society today. How to formulate a pathway toward a sustainable society is a critical question. Several issues associated with this question are presented and discussed. First, a structuring of the issues is presented. The environment can be said to consist of three systems—the natural, social, and human—and their interactions; environmental problems may therefore be defined in terms of perturbations of the interactions among the three systems. A sustainable society can be realized by restoring these interactions. Next, the characteristics of the issues are discussed. Because environmental issues relate to the future, forecasts of the future are essential. Because it is impossible to predict the future with complete accuracy, however, we should develop a method of using information about the future with allowance for error. It should be noted that error characteristics differ according to their time-scale. Third, the relationship between environmental issues and society is discussed. To take collective action on these issues we need society-wide consensus, which requires a reliable and objective platform. Here, more attention must be paid to the distribution of knowledge across society, because scientific knowledge in a modern society tends to be monopolized by research organizations. The role of the media is therefore important. Another important factor is the commitment of the general public; user-friendly ways of galvanizing such commitment should be developed.

Keywords Sustainability · Prediction · Uncertainty · Integrated assessment model · Climate model

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Introduction

Hurricane Katrina had a profound impact on the world community by demonstrating the extent to which our modern society still faces danger from natural disasters. The damage, amounting to approximately US $75 billion, was among the largest in the world for a natural disaster. It should be noted that this disaster occurred despite advance predictions and the issuing of appropriate hurricane warnings. Although the reasons proper action could not be taken are manifold and complex, and difficult to summarize in a sentence, the Katrina disaster suggests we must reconsider how society should respond when probabilistic information about a future disaster is issued. Because there are many issues at stake in the choice of actions, a priority-setting process is also involved, which is in turn affected by many factors, for example the financial situation of the affected nation and the value systems and lifestyles of the inhabitants.

Environmental issues and the future sustainability of society are among the greatest concerns facing society today. How to formulate a pathway toward a sustainable society is a critical question. In attempting to answer it, it is crucial we consider just what an environmental issue is.

We often say that we are living in a natural environment, but this is not exactly true. Our living environment is manifold and consists of different systems. For example, most of us live in a society in which the economy is of great concern to us. It should be noted that we are not directly living in a natural system, but in a socioeconomic system, which is built on the natural system. At the same time, the socioeconomic system consists of individuals. Usually, political decisions are made by the government, which is elected by individuals. It should also be noted that these three systems—the natural (or global) system, the social system, and the human system—are mutually dependent. When we try to develop the social system in the interest of maximizing economic benefits, it can adversely affect both the natural system (e.g. in the form of environmental problems) and the human system (e.g. in the form of stress symptoms and mental health problems). Thus we need to pay closer attention to the interactions among these systems and develop a design for the society of the future accordingly (Komiyama and Takeuchi 2006). This point will be discussed in more detail in the section‘‘Interactions among the natural, social, and human systems’’.

A second point is that environmental issues are issues involving the future. They demand we act now because otherwise something untoward will happen in the future. To convince people of this we need reliable information about the future; this includes information not only about the natural system, but also about the social system. Many efforts, both scientific and technological, have been made to predict the future of the natural system and the social system, but all future forecasting is inevitably probabilistic, and no forecast can be made with certainty. It is, therefore, critical to develop a method by which careful and thoughtful action can be applied to environmental issues based on information obtained from predictions that accommodate uncertainty.

The problem, of course, is that if forecasting the future were a perfect science, no one would oppose taking some action to mitigate or adapt to predicted events, although there would remain uncertainty about what action should be taken. In reality, however, uncertainty in predicting the future is inevitable; it results from the characteristics of the systems involved and our lack of knowledge about these systems. For example, our climatic system is chaotic by nature and deterministic prediction of its future is, in principle, impossible. The same can be said for the interaction between human activity and nature. And it goes without saying we have little knowledge about the future of our society. How to deal with the uncertainty issue will be discussed inthe sections ‘‘Uncertainty in future simulations’’and‘‘How to use climate model results in light of uncertainty’’.

In the real world, action means allocation of funds, and there are many fields to which resources should be allocated. We cannot, however, allocate funds to all fields in need. We have to make decisions about where our resources should go. Some argue that optimum resource allocation can be achieved through a market mechanism whereas others insist that the market mechanism fails to allocate resources to the most important issues, for example the environment and ecological measures. Although there is debate on how to allocate resources, there are many points on which people can agree. There are many stakeholders in a society whose interests often conflict, however. For individuals decisions are a matter of individual responsibility but for nations decisions are made by governments, which are endorsed by elections. It is therefore important to achieve a consensus among people on a particular topic. For this it is critical to share knowledge, including data, scientific and technological findings, and perceptions. In particular, society must share a common perception of the future—i.e. what will happen in the future. In this regard the relationship between science and politics is important.

It is easy to say that the present generation should take action for the sake of future generations. In reality, revenue is limited and financial conditions are severe for most people, and many have doubts about making definite decisions about the future. It is, however, also clear that many people have realized we must take some action for the future of the Earth. To achieve a consensus in society to mitigate or adapt to environmental problems it is therefore important to discuss how to utilize information in the light of its uncertainty. This point will be discussed inthe section ‘‘How to achieve a social consensus’’.

In this paper, different aspects of environmental issues will be discussed in the context of global warming.

Interactions among the natural, social, and human systems

In this section we will discuss different aspects of the interactions among the natural system, the social system, and the human system. Global warming is one example of interaction between natural and social systems.

The climate of the Earth is determined by the law of conservation of energy. The Earth is heated by solar radiation. Heat is then emitted by the planet back into space. If the incoming energy is greater than the outgoing energy, the temperature of the planet continues to increase and, when the incoming and outgoing energies are equal, the increase halts and a steady climate is maintained. In short, the climate of the Earth is determined by the energy balance between the planet and outer space.

The main reason why global warming has occurred is that human activity has the potential to disturb this energy balance. The Earth's climate is controlled by the radiation balance between the Sun and the Earth (Fig. 1). Incoming solar radiation is reflected, scattered, and absorbed by clouds, water vapor, and aerosols in the atmosphere. Almost half of the solar energy incident on the top of the atmosphere reaches the surface. The energy absorbed by the Earth's surface is then transmitted back into space by different mechanisms. Many processes are involved in the Earth's radiation balance, which means the balance can be perturbed by many factors (Manabe and Wetherald 1975). For example, it is well known that the solar intensity at the top of the atmosphere is not constant, and its variability causes climate change. Volcanic activity is another example. When a volcano erupts it distributes ash and aerosols in the stratosphere, which tend to cool the Earth. Here it should be emphasized that the Earth's radiation budget is strongly controlled by atmospheric composition. For example, sunlight penetrates to the Earth's surface but does not reach the bottom of the ocean, because the characteristics of solar absorption are different in the atmosphere and in liquid water. The characteristics of the absorption and emission of solar radiation and Earth radiation depend on the composition of the atmosphere, which is not steady. For example, oxygen in the atmosphere results from biological activity. In 1974, Lovelock and Margulis (1974) presented the famous ''Gaia hypothesis'', which proposed an interaction between the climate system and the biosphere. A debate about its validity ensued, and there is no consensus about the Gaia hypothesis, but there is no doubt that the composition of the atmosphere has been changed by many factors, including the effects of the biosphere. It is therefore important to recognize that human activity has become substantial enough to perturb the radiation balance of the Earth's climate and that the human effect has become comparable with natural factors. In other words, human beings can modify the atmosphere's composition by emitting greenhouse gases and aerosols, and by changing the land use and land cover of the Earth's surface. Future changes in energy use and land use are highly dependent on future socio-economic conditions (lifestyles, economic circumstances, etc.) and on technology development.

Another example of interaction between the natural and social systems is material flow. Energy is not the only component relevant to a discussion of the Earth's climate; materials are also important. For example, carbon is removed from the atmosphere by photosynthesis on the Earth and returned to the atmosphere by respiration. Humanity has produced many artificial materials, however, some of which cannot be recycled through the natural system. If they cannot be recycled they remain forever, resulting in accumulation of waste matter. Again we should realize that human activity is so great that it affects energy and material circulation over the entire planet. For example, Japan imports chemical fertilizer from abroad. This is an artificial inflow of nitrogen which causes eutrophication and perturbs the ecosystem in Japan.

Global warming is not only an issue of interaction between the natural and social systems. The global-

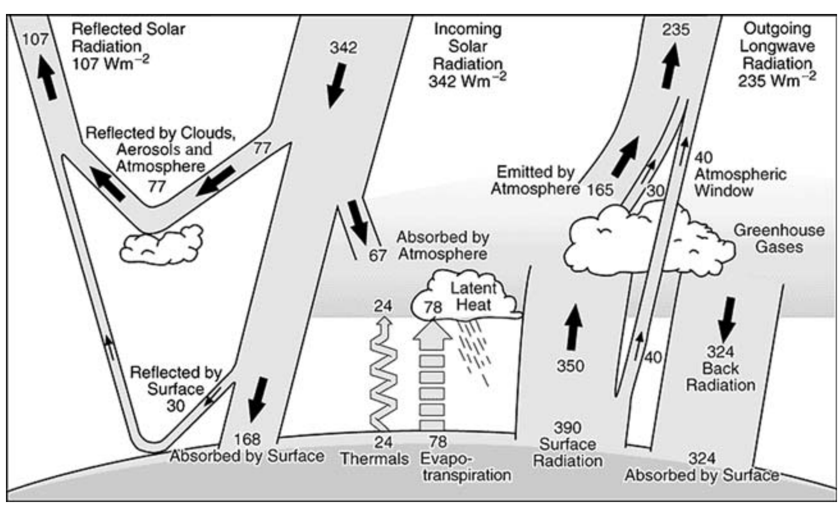

Fig. 1 Radiation budget for the Earth from IPCC TAR (2001)

warming issue is strongly connected to the energy issue, and energy is one of the key elements of modern society. These issues are therefore collectively referred to as a trilemma or 3E (Energy–Economy–Environment) problem. Different options for mitigation and adaptation have been presented for solving this problem. Occasionally, however, people's values and subjective preferences play an important role in choosing policies and technologies. We should keep in mind that the value systems of people are a significant factor in the effort to establish a sustainable society.

Here I would like to point out some similarities between the global-warming issue and the issue of nuclear weapons and their abolition. First, both are global in the scale of their influence. If nuclear weapons are used they threaten everyone's existence, whether one is responsible for their use or not. With global warming, also, everyone in the world will be affected by a changed climate, even those who are not responsible for the warming. Next, both are problems that may occur in the future. The difference is that the catastrophic consequences of the use of nuclear weapons are well recognized whereas the consequences of climate change are not universally recognized, although awareness of the dangers of climate change has risen with the recent increase in abnormal weather events. Third, to prevent such a catastrophe from occurring we must accept some limits of our freedom. To reduce or abolish nuclear weapons, each country must voluntarily forego the freedom to increase its military power. To mitigate global warming, each society must accept constraints on its freedom to maximize its own economic interests. People can insist on the right to pursue their own interests; occasionally, however, people have to give up even those rights. Fourth, action on both issues is accelerated by the support of the general public. Finally, it should be pointed out that both issues impose constraints on global politics and the economy; thus the actions required to address these issues demand international diplomacy. For reduction of nuclear weapons the Nuclear Nonproliferation Treaty was concluded. For the global-warming issue long-lasting international diplomacy is being pursued through the activity of the United Nations Framework Convention for Climate Change Conference of Parties/Meeting of Parties (UNFCCC COP/MOP). The Kyoto Protocol is one successful result, even if the future of the protocol is unclear.

To design a stable system, negative feedback must be introduced. For example, when a negative effect of the social system is identified, action to remedy that effect must be initiated. These continuous actions to remedy problems are very important. For this purpose, information about what is happening and what is the truth is critical. Although a globally distributed network of information makes people aware of what is occurring now, we must also recognize that many types of stable system are possible and we have to select the stable system that will make people happiest. At present, most governments are compelled to pay attention to public opinion and to the activities of nongovernmental organizations (NGOs). One example is the reaction of society to the deforestation of the tropical rainforest, which has received global attention particularly through the ''fish-bone'' features visible in satellite images of the Amazon (Fig. 2).

Besides the objective interactions among natural, social and human systems, subjective aspects of human beings must also be taken into account. We have to design a future society that maximizes the happiness of both the present and future generations. The meaning of happiness may differ for each individual, however, and for different cultures. These differences must be taken into account. But how? An issue-driven approach is required. First we must define the issue, then investigate the structure of the issue and list the requisite knowledge available, together with the interrelations among different disciplines. Next, we must organize scientists and engineers who possess this knowledge. We need to develop a method of integrating such knowledge; for this a transdisciplinary approach is critical, so a method of coordinating different disciplines must also be developed. Currently such efforts are conducted on a trial-and-error basis. Finally, whether this coordination is successful or not

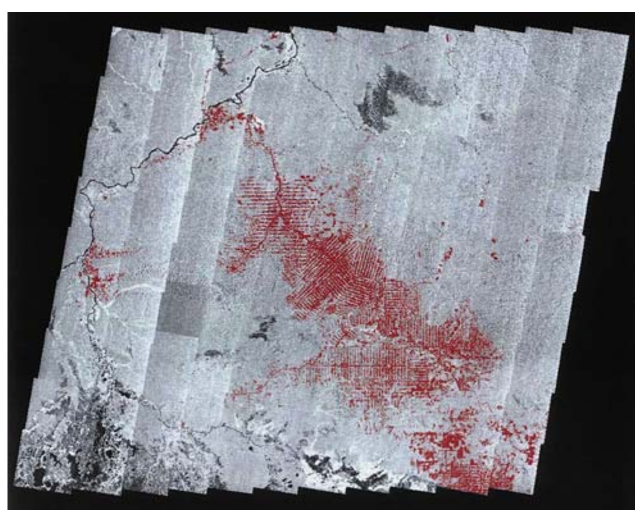

Fig. 2 Fish-bone features in the Amazon Basin observed by the synthesis aperture radar (SAR) of the Japanese satellite Fuyo, indicating deforestation of the rainforest in the Amazon Basin

depends on the ability and leadership of the organizers; we must therefore prepare an environment capable of producing such organizers. For this, a physical venue should be established where representatives of different disciplines can meet and attempt to organize their respective disciplines together. This is exactly what the transdisciplinary initiative for global sustainability (TIGS) at The University of Tokyo[1] is attempting to do.

Uncertainty in future simulations

As explained in the "Introduction", to make decisions on environmental issues we need to know what will happen in the future. For example, global warming is a problem that will certainly grow in the future, notwithstanding current debates about whether or not it is already occurring. It is, moreover, a problem that has a time horizon. For this reason, forecasting and future simulation are critical. In other words, it is impossible to make reasonable and optimal decisions about global warming without reasonable and reliable future projections.

The Earth's climate is predicted by using a model to simulate it. Here, it should be noted that a climate model is developed from scientific knowledge accumulated as a result of the efforts of scientists and can thus be said to be an intellectual asset of the human race. Climate modeling is the only reasonable way of forecasting the future. For details on climate modeling, refer to Trenberth (1992).

As mentioned in the "Introduction", however, "perfect" predictions are, in principle, impossible. For example, simulation results of global warming projections for globally averaged surface temperature increases and precipitation increases are presented in Fig. 3, which displays the equilibrium response of surface temperature and precipitation as a result of doubling of the amount of CO_2, as given in the IPCC second assessment report (SAR) and in the third assessment report (TAR). They seem to be scattered along a line. When we are developing a climate model, we usually change subroutines and variables in the model. As an example, model results from the Center for Climate System Research (CCSR), The University of Tokyo, are also displayed in Fig. 3. In this example we changed the subroutine of the boundary layer and cloud scheme (A) and changed the table of absorption coefficients in the radiation table (B). It is clearly

[1] For further information, see the TIGS Website at http://www.ir3s.u-tokyo.ac.jp/tigs/.

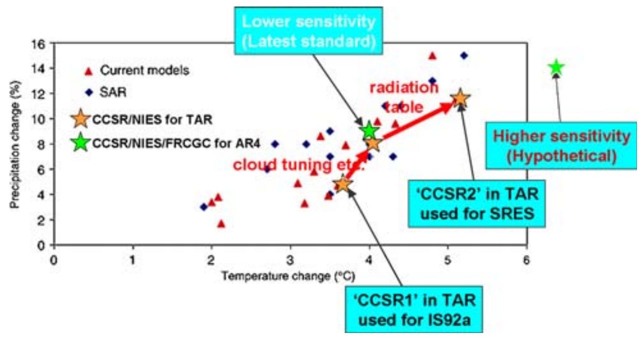

Fig. 3 Equilibrium climate sensitivity in IPCC SAR and TAR models; CCSR model results are also shown. The *arrow*labeled "*cloud tuning*" corresponds to (*A*) in the text and the *arrow*labeled "*radiation table*" corresponds to (*B*) in the text

understood that results from different research centers and results of one model with different components are distributed within a certain range. This is defined as a climate-sensitivity issue (Murphy et al. 2004).

Here, it should be noted that the anomaly attributable to global warming is estimated by subtracting the current climate simulation from the warmer climate simulation. This procedure assumes that model errors are similar in the current climate and warmer climate simulations and cancel out. If errors in the current climate and warmer climate simulations do not cancel out, it is obvious that differences of an order of several percent of the mean values will appear.

On the basis of the discussion above, we will now examine the results of simulations. The time sequence of the globally averaged surface temperature (Ts) from different models is displayed in Fig. 4. It is certain there are differences at the year 2100, but the reader should pay attention to the earlier period. When one examines the first 30 years, i.e. 1990–2020, almost all the model results reveal a similar trend. The warmest result is given by the MIROC-hi, which is our model, but until 2030 its trend is similar to that of the others.

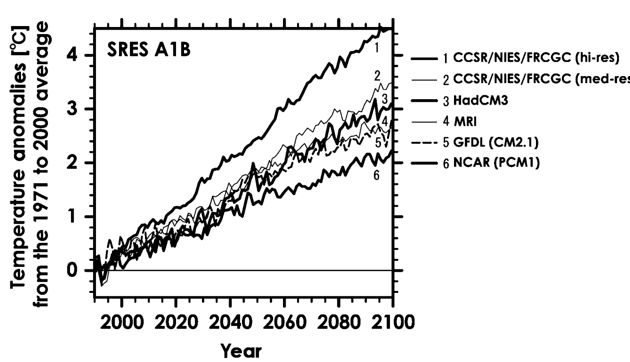

Fig. 4 Globally averaged surface air temperature change in IPCC AR4

The 30-year period is important practically. If we have to develop an infrastructure to adapt to global warming, it will take 30 years to complete it. Thus we need to make decisions based on information about the climate 30 years hence.

When we discuss differences in model simulations for 2100, however, we may assume that they arise because of many uncertain processes and variables. We should also consider the possibility that an assumption of linearity and common errors is not true. We can thus conclude that the extent of the error differs according to the time-scale. In other words, we may consider there is a short-term ‘‘prediction’’ time-scale and a longer-term ‘‘projection’’ time-scale. The difference in character of the error does not, however, necessarily mean that simulation results on the prediction time-scale are reliable. We have to examine the quality of the simulations.

In the 30-year prediction model, the assumption that change is small and model errors are canceled out may be true. It then becomes an issue of whether or not natural variability can be represented, because this variability appears as noise in the signal of global warming. Within natural variability, El Nino southern oscillation (ENSO) variability and decadal fluctuation, for example the Pacific decadal oscillation (PDO), are dominant. So far, ENSO and decadal variability are, to some extent, included in global warming simulation. Our ability to represent this natural variability should be validated by using past observations when we apply our model to past data.

In validation of climate prediction the main issue is lack of data. Data insufficiency is one of the critical issues confronting climate studies. For the atmosphere we have sufficient data after World War II and different re-analyses of data sets have been provided. We need observations of other components in the climate system also, however. Besides the atmosphere, ocean status is critical. In other words, we need to reconstruct the ocean status of the twentieth century, but observational data are limited and how to reconstruct historical oceanic states is a serious issue. Data on the ocean interior are particularly limited. The only available historical information is in the form of marine observations at the ocean surface. Marine surface observations are more abundant than subsurface data, but a relationship has been noted between sea surface temperature and subsurface temperature. Reconstruction of ocean status has been based on these empirical relationships (Ishii et al. 2003; Levitus et al. 2005).

It is believed the deep ocean state has little effect on the 30-year time-scale, however; the ocean state is also regarded as being forced by the atmosphere, so if we insert atmospheric states and marine observations into a coupled model we can expect that upper ocean states (to several hundred meters in depth) can be reproduced. Here it should be emphasized that errors associated with emission scenarios can also be estimated. When we run a 30-year prediction, we use a particular emission scenario. As we have real emission results, we can evaluate the errors associated with different emission scenarios.

When initial states of the climate system have been obtained we can run a 30-year simulation from a particular date (e.g. 1960). We can then validate the 30-year simulation by observation at 1990 (this is called a ‘‘hindcast’’ experiment). As uncertainty because of the initial states and physical processes remains, we have to employ an ensemble method. Perhaps 10–30 samples are both possible and necessary. This is a climate state simulation and we have to use annual and seasonal averaged values, but even after 1960 we can select more than 15 examples, e.g. 1960–1990, 1961–1991, up to 1975–2005. On the basis of these simulations we can evaluate the errors in simulation, and on the basis of these error statistics we can then estimate a signal-to-noise ratio in human-induced climate change. The probabilistic density function (PDF) of each prediction is given using these ensemble results. Future predictions with error estimates and PDFs can be used in many fields of application. When we compute an effect of global warming we can add error and PDF information for this impact estimate. This information, with its reliability, is the first step in the generation of a consensus on an adaptation strategy.

How to use climate model results in light of uncertainty

To take any action toward a sustainable society we must make a decision about the future, although we cannot predict the future completely. As described in the previous section, we can predict the future with some probability within the prediction time-scale. With this time-scale error statistics and the PDF of predictions are provided; we must then determine how to use this information. For example, there are disasters that occur less frequently but inflict more damage on society and others that occur more often but inflict less damage. It should be noted that these damage amounts are estimated from current climate data, but they will certainly change with changes in society. It is no easy task to evaluate such damage, which is represented as an amount of money. Effects of global warming are currently given with approximately estimates of accuracy (IPCC 2001). When a PDF for climate change is provided, however, we can assign more accurate probability to these effects. In the future, further investigation of how to evaluate the PDF of such impacts is needed. When the probability of an effect and the extent of damage are given, we can compute the expected cost of the damage. Although there are many difficulties to resolve, the expected cost of the damage may play an important role in the decision-making process. Strategic thinking based on this quantitative information is necessary to allocate our resources toward mitigation of such disasters.

The required projection time-scale is approximately 100–300 years, however; it is, therefore, impossible to eliminate uncertainty because there are so many unknown processes and the future of our social system is also unpredictable. On this time-scale, simulation should be viewed as a ‘‘gedanken experiment’’, and simulation results should be summarized descriptively and qualitatively. Such simulation can be used to determine long-term objectives for our society, however, when an error of the order of 1–3 K does not have a significant impact. Examples of the general conclusions reached from results from 100–300 year projections are:

(1) If greenhouse gases increase in the atmosphere, the global mean surface temperature will not decrease. In other words, if the concentration of CO_2 in the atmosphere increases, a cold climate will never arise.
(2) If the present emission level is maintained, the future climate will get warmer, but the warming is of an order of a few degrees, not several tens of degrees. In other words, human beings will not become extinct as a result. That amount of warming is currently manageable.

On the basis of these conclusions we can discuss the future direction of society. We can, for example, discuss whether the society of the future should be an energy-efficient society or a zero-carbon society or a nuclear energy society. Because a warmer climate is inevitable, however, it can be concluded our objective should be a zero-carbon society and that renewable energy technology should be developed, irrespective of any projection. When the future direction is set, detailed options for adaptation can be evaluated by applying a 30-year prediction.

Although it is important to develop a quantitative method for using probabilistic information about the global-warming issue, we should keep in mind the concepts behind this issue. One of the basic concepts is equity between the present generation and future generations. For example, we have to reduce our energy consumption as a mitigation measure for the sake of future generations. We are trying to achieve a consensus for this action, but it is not easy, because of such problems as the conflict between developed countries and developing countries. The issue of equity between generations is related to many different issues. For example, the percentage of senior citizens has increased in Japan, and we can predict the future status of Japan on the basis of this fact. The future financial burden on the country’s social welfare system is currently a significant political issue. It can be said that benefits are being taken by the present generation, although costs will be borne by future generations. This is not a social welfare issue, however, but rather an economic issue between current and future generations. Equity between generations is a very important concept and we should not ignore it. If most of the people in society shared this view, consensus could be obtained for many options leading to a sustainable society.

Finally, because the future is related to the life of each individual, economic values and personal views are important. These cannot be separated from individual value systems and ideologies in the process of seeking a consensus about the future of society. In this sense, the future is not uniquely defined, but diverse.

How to achieve social consensus

Global warming is an example of an issue for which science and policy are connected. Similar examples include ozone-depletion and air-quality issues. There remains a large gap between the two groups, however. Scientists can tell politicians what they know, but policy demands all necessary knowledge. Usually what policy requests is more than science can provide. The question may arise of whether science is useless for political decisions. The answer is in the negative. In any event, we need science. In the present political world, scientific and technological knowledge are indispensable to political decisions, because present-day issues cannot be handled without such knowledge. The difficulty lies in convincing politics about what science has to offer. The reason politics often cannot accept what science suggests is, usually, science tells a story derived logically from data and assumptions whereas politics must pay attention to different aspects of human beings, for example, greed, fear, and economic concerns. It also relates to the value system and mental state of each individual.

Currently, because it is assumed a warmer climate is inevitable, we should be preparing for a sustainable society in a warmer climate. When we consider an adaptation strategy for a warmer climate we must take into consideration a broad diversity of stakeholders. In general, society consists of many stakeholders whose interests and values vary. These stakeholders tend to request that governments allocate money to their particular fields. For example, someone will argue that resources should be used to maintain agriculture, to prevent a degradation of the natural environment. Others will insist that resources should be allocated to the development of new energy technology. Every action plan has a supporter and an opponent. So how to proceed? How do we achieve agreement across society? If we have a comprehensive knowledge of the different components of society such decisions are possible. When conclusions are presented to stakeholders, however, it is usually difficult to persuade all of them of the validity of these conclusions, because their values and standards are different.

To achieve consensus in society we need a common and objective platform on which the effects of different policies and options can be examined and evaluated. This will facilitate the development of conclusions that accommodate different stakeholders. One candidate for such a platform is an integrated assessment model coupled to a climate model, so the integrated assessment model can evaluate many aspects of social activity under climate change and the climate model can predict the climate change resulting from human society. In other words, the model should include not only physical aspects but also socioeconomic aspects and their interaction. Again it should be emphasized that the 30-year prediction discussed in the section "How to use climate model results in light of uncertainty" plays a major role, because the reliability of such projections can be presented. The model should also be examined by many researchers with different opinions. On this basis we can report the effects of a given option on future society with some probability. For example, there are many options for an energy policy for mitigation and adaptation to global warming, for example a carbon tax and an emissions trade. We can evaluate the effect of each option by using this integrated model.

Again, however, it should be noted that a perfect model is impossible. It is natural there are many different estimates based on different political options. It is, therefore, crucial to establish the concept of neutrality and commonality of the platform in society. To ensure neutrality, a research organization independent of government ministries should be established, where development and maintenance of the platform and evaluation of options can be conducted. To withstand pressures from different sectors, its financial base should be sound. If a government can set up this common platform to evaluate the effects of different policies, it will be much easier to make objective and optimum decisions about future resource allocations.

Another important factor is the distribution of knowledge throughout society. As science and technology advance, centralization of knowledge tends to occur. In other words, essential information and knowledge tend to be monopolized by a particular group. Government actions are usually discussed among specialists, for example scientists, bureaucrats, politicians etc. Their decisions are then reported to the public through the media. When we are informed of results only, however, we are less likely to be convinced of their merit. This tends to cause suspicion among citizens about government decisions, and this suspicion is an obstacle to the achievement of consensus in society. Consensus can usually be more readily achieved by sharing scientific results with the citizenry. One good example is the work of the Intergovernmental Panel for Climate Change (IPCC); their scientific and technological findings and information about global warming are summarized and presented to society in IPCC reports (e.g. IPCC 2001). The role of IPCC in the policy-making process has often been discussed. One tentative conclusion by the IPCC is that the panel should be "policy-relevant and not policy-prescriptive". Although the function and effectiveness of the IPCC have been discussed, it should be noted that the framework has been approved by many nations and it will be used for other issues. For dissemination of knowledge to society, the role of the media cannot be overlooked. Although there are many relevant publications and programs in the media (Gelbspan 1997), further efforts should be made to establish conduits for communication with the public through the mainstream media.

The commitment of the general public is also important. They cannot, for example, currently gain access to details of global warming simulations. But if people can participate in the simulation process it may have an effect on them. One example is a "climatenet" (Staniforth et al. 2005), the purpose of which is to use idle computer resources in private homes for estimating climate sensitivity. Although there is debate about whether the participants represent the general public, it is significant that more than ten thousand people participate in this project.

If we can provide user-friendly software, for example game software with which we can predict the future climate by choosing one of several adaptation options, it would be a useful tool for convincing people of what needs to be done. Let us assume that different options for reducing carbon emissions are examined by use of such a system. When someone selects an option, he or she will be able to appreciate the sequence of climate change generated by that option. Through such activity people can become familiar with different scenarios about the future and with the characteristics of mitigation of and adaptation to global warming. This will contribute to the establishment of consensus on such issues in society.

Conclusion

To achieve the objective of establishing a sustainable society, several issues must be discussed. First, it is necessary to clarify the structure of environmental issues. It is our view that the environment consists of three systems—the natural system, the social system, and the human system—and their mutual interaction. Environmental problems can then be defined as perturbations of these interactions; to solve such problems we must find a way to restore these interactions. Research activity should be organized in accordance with this structure. It is particularly important to note interactions with the human system.

Environmental issues have a time horizon. To take action we need the agreement and support of society. For this purpose, it is necessary to present society with scenarios of the future. In this sense, our skill in predicting the future is critical and uncertainty is inevitable. For the global-warming issue, uncertainty is accommodated by providing probability data for each simulation, and results are presented to society in IPCC reports. Predictions by the IPCC are sometimes questioned, however, because there is little evidence to verify the validity of each prediction. In typical weather forecasting verification occurs every day, i.e. every forecast is verified by observation and the accuracy of the forecasts can be presented to the public.

Time-scales for global warming simulation should also be introduced, for example a prediction time-scale (approx. 30 years) and a projection time-scale (100–300 years). For the prediction time-scale we can estimate error statistics and the PDF of each prediction by use of hindcasts from 1970 to the present. The next step is how to apply the PDF information to effect studies and mitigation/adaptation policy.

To achieve consensus in society we need a common and objective framework from which the effects of different policies and options can be examined and evaluated. It is therefore proposed that an integrated model coupled to a climate model be used as a framework for evaluating different options for the future on a 30-year time-scale. If such a framework is to be effective, however, we must gain the support and trust of the public.

The distribution of knowledge throughout society and the commitment of the general public to the decision-making process are key to establishing a sustainable society. It is therefore important to establish a reliable scheme for disseminating accurate data to the public. The role of the mainstream media is significant, so we must find ways to disseminate knowledge through the mainstream media. Another factor is the participation of the general public. When user-friendly devices become available for helping people experience climate-change scenarios, more people can appreciate the future of the Earth's climate.

It should be remembered that decisions on the future depend on the economic interests and values of individuals. We should remember that people's happiness is not directly dependent on the natural environment. Most people's sense of well-being depends on the social and cultural system in which they are living. When scientific and technological knowledge advances further, we can present more reliable estimates of the future. This does not, however, automatically guarantee we can achieve consensus on the proper actions to take for the future. In parallel with the advance of our knowledge, our logic and ethics must also advance.

Finally, environmental issues affect many interactions among human, social, and natural systems. They also affect the future, so inevitably there are many difficulties and unknowns. When we are faced with these difficulties, we tend to be pessimistic. When we study history, however, we find there are many examples of human effort to overcome difficulties leading to a new age. Current issues also result from human efforts accumulated throughout history. We should therefore be optimistic, because that is the only way to trust in the possibility of our overcoming these problems.

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